

What is String Theory?



And, What Does It Have
to Do with Black Holes?



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Outline

I • The search for the basic building blocks of Nature



II • String theory

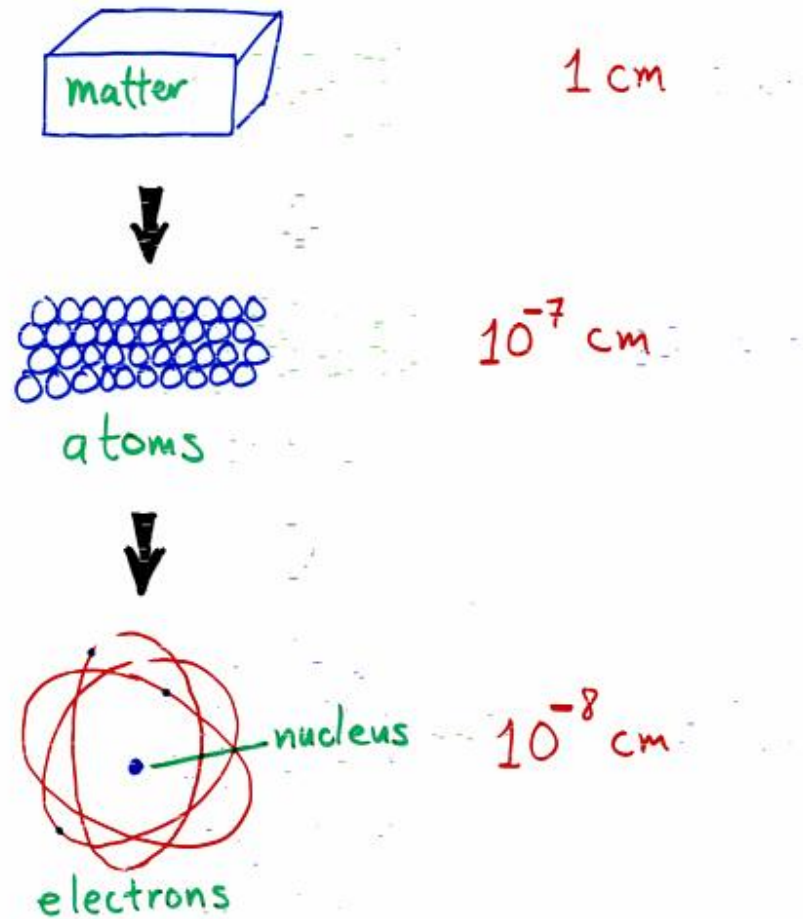


III • The conflict between General Relativity and Quantum Mechanics

IV • String theory as a scientific theory

V • Black holes

I. Science has found smaller and smaller building blocks:

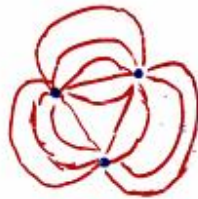


nucleus



10^{-12} cm

protons + neutrons



10^{-13} cm

quarks + "glue"

Questions:

- Are these the final building blocks?
- If not, what's next?
- Is there an end?

The basic building blocks today:
the "Standard Model" (including
general relativity)

18 kinds of quark (6 flavors
x 3 colors)

6 kinds of lepton (including
electron, neutrinos)

Higgs boson

4 forces: gravity, electromagnetism,
strong nuclear, weak nuclear.

≈ 1974. Works from 10^{-17} cm
to 10^{10} lightyears.

Goals:

- Explain the patterns in the Standard Model.
- Resolve subtle mathematical and physical inconsistencies.

Some past ideas:

- Grand unification
- Kaluza-Klein theory
- supersymmetry

These turn out to be pieces of a larger picture: String Theory

II. String Theory

Under sufficient magnification,

• ← quark, lepton, ...



← string

← 10^{-32} cm →

(vs. 10^{-15} cm of present experiments)

1 building block.

Different states of vibration
(harmonics) $\Rightarrow$ different particles:



$\Rightarrow$ quarks, leptons, Higgs, photon,
graviton, gluon, W, Z.

Strings can break + join:



$\Rightarrow$ all forces.

1974 ... 1984 ...

III. Conflict between GR and QM:

Two of the central theories in physics, General Relativity (GR) and Quantum Mechanics (QM) are in conflict with one another.

GR: Spacetime can bend - this is gravity.



QM: Nothing sits still (the uncertainty principle).

GR + QM: Spacetime doesn't sit still - it has "quantum fluctuations."



(Normally not a problem)

Not a problem at 1 cm.

Not a problem at 10^{-15} cm.

But:

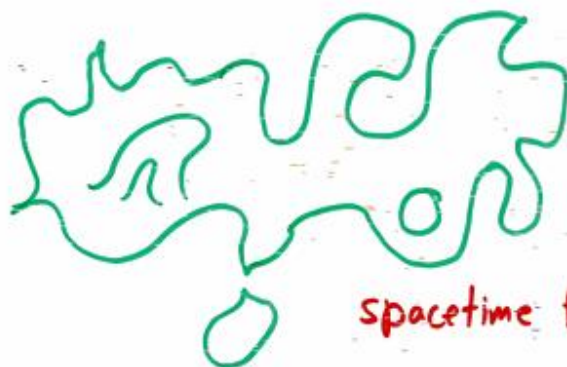
10^{-31} cm:



10^{-32} cm:

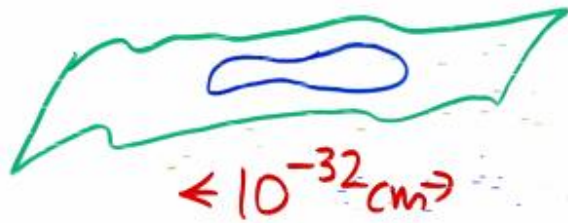


10^{-33} cm:



spacetime foam

$$\text{Planck length} = \sqrt{\hbar G / c^3} \approx 10^{-33} \text{ cm}$$



- String theory cuts off the fluctuations of spacetime (only known theory that does).
- * String th. includes both GR + QM.
- Distances shorter than the Planck length probably do not exist.

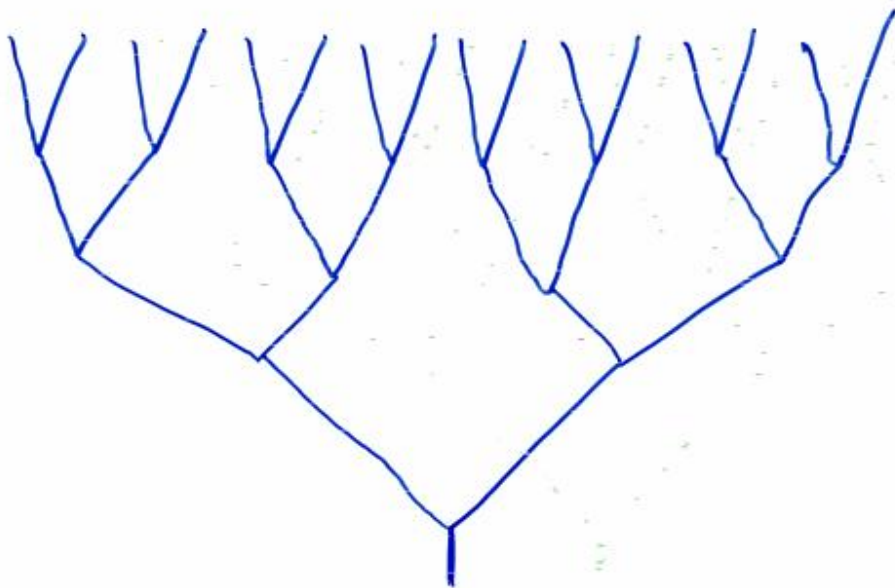
IV. Strings as a scientific theory

- Unusual: theory without ongoing experiment.

- Experiment has not yet seen inside quarks, leptons, ...

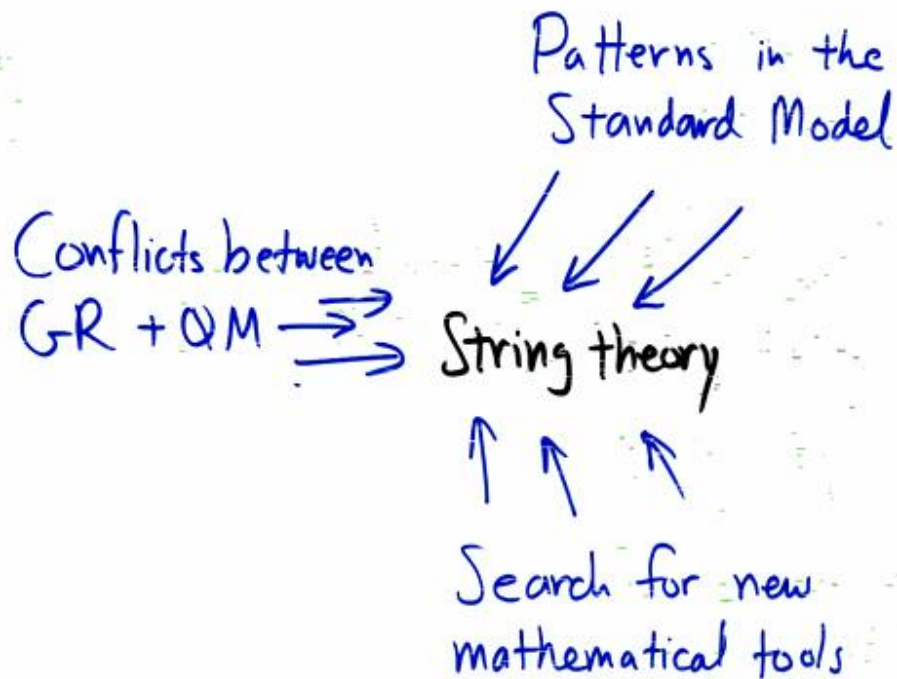
- Strings are so small that they will never be seen directly.

Theory without experiment:



Successive extrapolations →
multitude of theories

All roads lead to string theory:



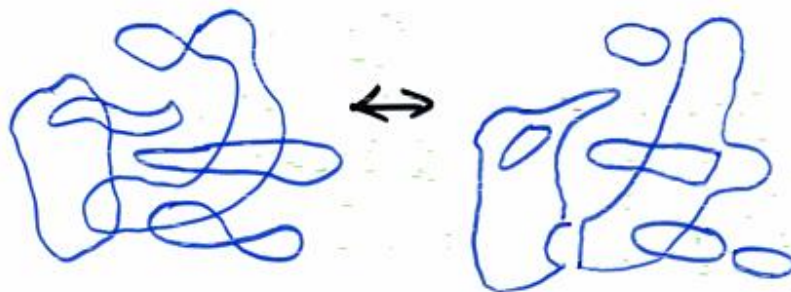
String theory is still evolving.

- We are still looking for the correct mathematical tools.

- Physical problem: we understand small numbers of strings interacting weakly



but not large numbers with rapid interactions:



Likely outcome: strings are not the end. For example:



We need a new name:

"The Theory Formerly Known as Strings"

"M-Theory"

M = membrane, matrix, magic, mystery, mother ?

"U-Theory"

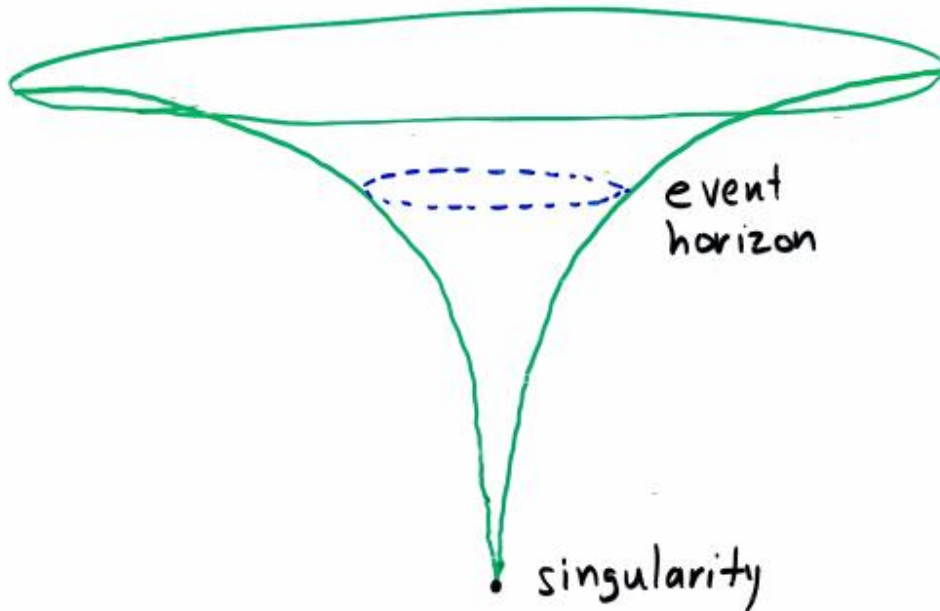
U = unknown, ur

V. Black Holes

Black holes are an extreme environment $\Rightarrow$ problems and puzzles for general relativity.

String theory, if correct, should resolve those puzzles.

black hole:

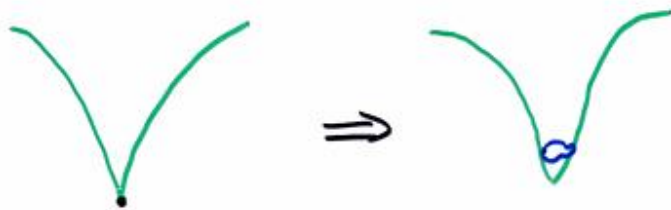


singularity: infinite curvature

horizon: point of no return

At the singularity, Einstein's equations break down. A more complete theory should fix this.

For certain singularities (though not yet the black hole singularity) this is known to work:



(B.R. Greene,
"The Elegant Universe")

Puzzles at the horizon:

#1) There is a close analogy between the laws of black hole mechanics and the laws of thermodynamics. Example: horizon area always increases / entropy always increases.

⇒ This suggests that the black hole horizon has an "atomic" structure, with horizon area $\propto$ disorder.

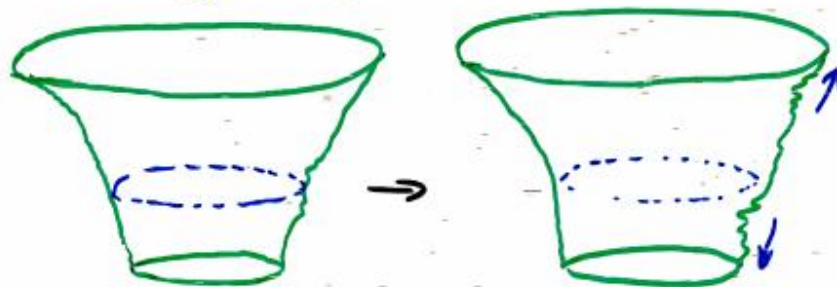
Recently (1995-98) it has been shown that string theory implies such an atomic structure:



D-branes (new structures in string theory).

- Horizon area = entropy (disorder) of D-branes.
- D-branes (probably) store and reradiate information.

#2 Hawking radiation:

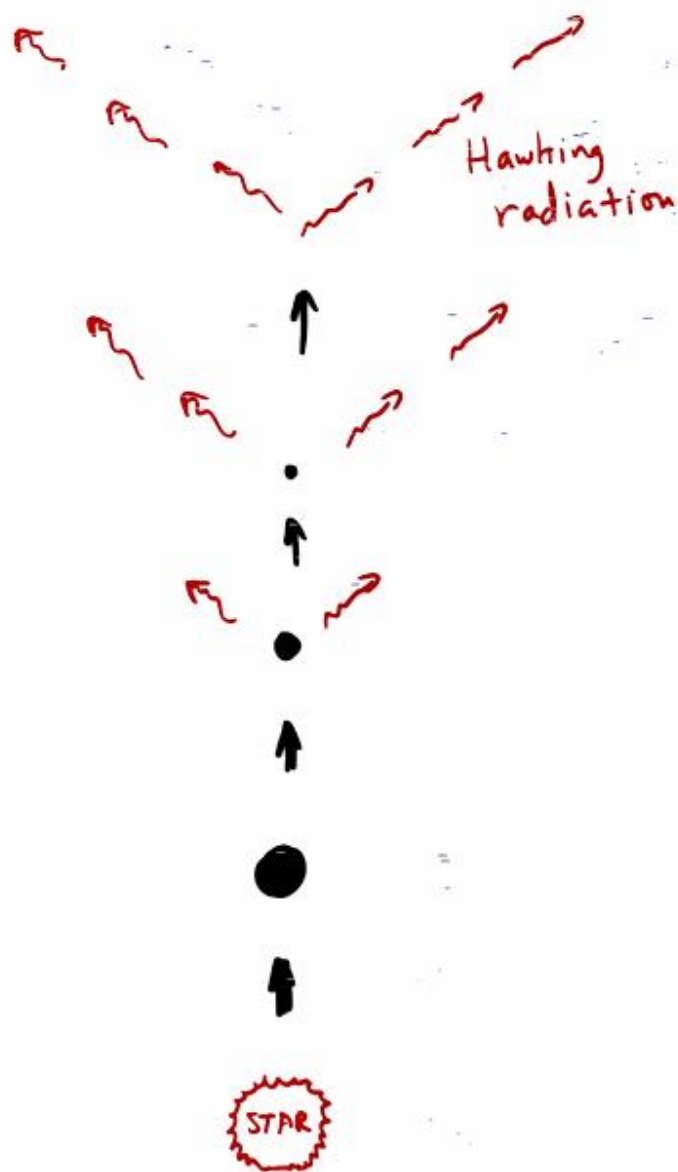


Quantum fluctuation near horizon can separate, with half escaping to outside as light or other radiation.

⇒ Black holes are not really black.

⇒ The horizon area does decrease, but area + entropy of radiation increases.

⇒ Black holes eventually evaporate + disappear. (Very slow for big black holes)



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When the black hole evaporates and disappears, it erases all knowledge of what fell in during its lifetime.

"Information loss."

- This is inconsistent with quantum mechanics.

Alternatives:

- Modify quantum mechanics to allow information loss.

- Modify spacetime to allow information to be imprinted on Hawking radiation.

•

Hopes for experimental test:

- Discovery of supersymmetry at particle accelerators (next 10 years?)
- Improved theoretical understanding
 - ⇒ • precise predictions of particle properties
 - cosmological tests
 - surprises.

Extra dimensions:

